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before the

Blue Ribbon Commission on America's Nuclear Future
Transportation and Storage Subcommittee
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Thank you for the opportunity to address the subcommittee on transportation and storage of the Blue Ribbon Commission. It makes little sense for some of us to drive hours just to appear five minutes before the subcommittee. If members of the subcommittee have questions or wish additional references, I would be happy to address requests in writing or appear in person if more time were allotted.

By way of introduction, I graduated from the University of Michigan in 1965 in the area of group theory and particle physics. Beginning in 1974, as a volunteer of the Sierra Club, I began examining reprocessing issues concerning the former Nuclear Fuel Services (NFS) reprocessing plant in West Valley, New York. NFS was the only commercial reprocessing operation in the United States. I first began investigating transportation issues in 1975 for New York's Attorney General Louis Lefkowitz on the issue of liquid plutonium being flown out of New York's JFK airport. AG Lefkowitz sued the Nuclear Regulatory Commission to prevent these shipments. I have since remained up to date on issues involving reprocessing, transportation and storage of radioactive waste. I am a consultant to the State of Nevada on transportation issues, though the remarks herein are mine alone and do not necessarily reflect the views of the State. I have authored or co-authored four books on radioactive waste issues, including a book on transportation issues[1]. In the year 2000, I served on Secretary Bill Richardson's Blue Ribbon Panel on alternatives to incineration of radioactive waste. I also visited the proposed repository in Sweden, though these remarks do not directly pertain to that subject.

This statement discusses two issues: 1) whether reprocessing is a waste management solution and 2) the arguments in favor of long-term storage of irradiated fuel at local or regional reactor sites.

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[1] Resnikoff, M, *et al*, *The Next Nuclear Gamble*, for the Council on Economic Priorities, New York (1983). This book is being updated.

Reprocessing

Reprocessing has been touted as a waste management solution, particularly by the national laboratories that stand to gain research dollars. Supporters of reprocessing also cite as advantages, security – a means of burning plutonium, and energy independence – a means of recycling and reusing nuclear fuel and reducing the need for additional uranium. All these arguments are unadulterated eyewash. Further, reprocessing is certainly not cost effective; the nuclear industry is not rushing to the banks to get loans to build reprocessing plants. Let me go through these arguments one by one.

PUREX and Pu Recycle

The standard PUREX (Plutonium and Uranium Extraction) reprocessing technology, in use since the Manhattan Project, separates out the plutonium (Pu) from uranium (U) from fission products. Irradiated fuel is first dissolved in acid. An organic solvent, kerosene laced with tributyl-n-phosphate, is added. The uranium and plutonium preferentially remain with the organic solvent, while the fission products remain with the acid. Uranium is then separated from plutonium. The radioactive fuel cladding hulls and process wastes remain and are buried in surface landfills. Fission products and actinides, such as neptunium, curium and americium, remain as high-level liquid waste that must be solidified.

Under reprocessing, some long-lived actinides, such as neptunium, and some long-lived fission products, such as technetium-99, remain in part with the uranium[2], but almost all these radionuclides, greater than 95%, are associated with the high-level waste (HLW). Technetium has caused great problems at the gaseous diffusion plants since TcO_6 volatilizes at approximately the same temperature as UO_6 and must be trapped to prevent it from entering the environment or leaving with the enriched U product.[3] At the Portsmouth gaseous diffusion plant, there has been extensive technetium contamination. Some long-lived fission products, such as iodine-129, remain in the process wastes and also in the fission product high-level waste (HLW). Iodine concentrates in the thyroid and increases the likelihood of thyroid cancer.

Perhaps it goes without saying, but commercial reprocessing has been a commercial, safety and environmental failure. At West Valley, the cost of the reprocessing plant, in 1963 dollars, was $32 million, mostly subsidized by the State of New York. The company brought in revenue of $21 million over its 6-year operating

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[2] IAEA (2003)

[3] dela Merced, M, B Hintermann and M Resnikoff, "Groundwater Movement at the Portsmouth Gaseous Diffusion Plant," Radioactive Waste Management Associates, report prepared for PRESS and the Uranium Enrichment Project, February 2002.

history. The cost for managing the waste, including decommissioning and cleanup of groundwater, is estimated at $5 billion or more. In terms of worker safety, the average radiation exposure in 1972 was 7.2 rems per worker, with some workers receiving almost 12 rems. Though these exposures are high by industry standards, they would have been higher yet had the company not hired hundreds of temporary workers, some just 18-years old, to do high exposure jobs.

Uranium Recovery

Under this PUREX stage, the Pu would be recycled into mixed oxide fuel (MOX). To have self-sustaining Pu production, the reactor recipe must be approximately one part MOX fuel (where Pu is mixed with natural U) to 2 parts enriched uranium fuel. That is, under this plan, the recovered uranium, which has less fissionable U-235 than natural U, is not recycled. However, recovered U contains U-236, a neutron poison, requiring a higher percent of fissionable U-235 and Pu-239+241. Since 1/3 of the reactor core would use natural (not enriched) U, there is a natural resource saving at this stage, in that less U ore would have to be mined. In order to produce 30 tons of enriched U fuel needed to operate a 1000-megawatt pressurized water reactor for a year, about 272 tons of natural uranium must be fed to the gaseous diffusion plant. Because ore in the U.S. contains a mere 0.15% uranium, approximately 180,000 tons of U ore must be mined to produce the 272 tons of U fed to an enrichment plant. Thus, to a small extent, using 1/3 part natural uranium does conserve U resources and also the energy needed to enrich U in the fissionable isotope U-235.

Because of its low U-235 content, uranium tailings are of little use; the Department of Energy is in the process of solidifying this material. Storage of U tailings at gaseous diffusion plants is a major environmental problem. Many of the UO_6 containers are rusting out.

Reprocessing as a Waste Management Solution

In terms of volume, heat and toxicity, simply recycling Pu does little to reduce the repository burden. Since the fission product high-level waste contains americium (Am), curium (Cm) and neptunium (Np), this waste will remain toxic essentially forever. Over time, Am-241 decays to Np-237 (half-life, 2 million years), and I-129, with a half-life of 16 million years, implies HLW will remain toxic, essentially forever. This can be seen in Fig. 1. It is important to note that Fig. 1 does not take into account I-129 and also the buildup of actinides when Pu is recycled several times. Nevertheless as seen, the HLW hazard is greater for MOX fuel (shown in the figure as PWR-Pu fuel) than standard U fuel. The continual recycling of Pu in MOX fuel leads to the buildup of greater amounts of Am, Cm and higher isotopes of Pu. Comparing U to MOX fuel where the Pu has been

recycled 5 times (Type E fuel), 8 times as much Pu-242 and Am-241 are created, 7 times as much Cm-242 and 15 times as much Cm-244. This is shown in Table 1, taken from the NRC's GESMO EIS[4]. These alpha-emitting radionuclides increase the heat production and toxicity of high-level waste. The heat production of HLW is important because the high-level waste (HLW) repository will have a limit on the heat production or power per acre (kw/acre) implying that MOX HLW will have to be spaced further apart. In short, under the standard reprocessing scenario, neither the hazard, nor the heat output of HLW is reduced. In terms of radiotoxicity, because of the buildup of actinides, spent MOX fuel is 8 times more toxic than spent U oxide fuel.[5]

While the volume of HLW in the repository is a function of the power output, the industry also considers the volume of the waste itself and claims there is a waste volume reduction in the PUREX process. The waste form being considered for HLW is borosilicate glass. In terms of waste volume, the borosilicate glass waste volume is many times greater than the original volume of the spent fuel sent to the reprocessing plant. To chemically separate Pu, U and fission products, chemicals must be added to the mix – nitric acid, kerosene, tributyl-n-phosphate, among others. The liquid HLW must then be solidified with glass frit to produce solid borosilicate glass. At the former West Valley reprocessing plant, the volume of solidified HLW compared to spent fuel was approximately 25 to 1. This increased volume primarily affects transportation impacts to a repository, but not the volume occupied within a repository since the volume occupied within the repository is primarily based on the heat output.

In addition to repository considerations, it is also important to evaluate the amount of other waste produced at the reprocessing stage. Cladding hulls would generally be disposed at a surface landfill, along with other so-called "low-level waste." Process wastes, generally spent chemicals in reprocessing, would also go to a radioactive landfill.

Advanced Fuel Cycle

In order to ease the repository burden, or as DOE describes it, to obtain "the full benefit envisioned for the separations process," several modifications must be made at the reprocessing stage. Essentially, the reprocessing stage requires several additional chemical steps, so that long-lived minor actinides (MA), such as Am, Cm and Np, and long-lived fission products, such as Tc-99 and I-129, are removed from HLW. Once these actinides and fission products are removed, they must be managed in some manner.

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[4] Nuclear Regulatory Commission, "Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors," NUREG-0002, August 1976.
[5] International Atomic Energy Agency, "Partitioning and Transmutation: Radioactive Waste Management Option, " Workshop on Technology and Applications of Accelerator Driven Systems (ADS), ICTP, Trieste, Italy, 13-17 October 2003.

These materials obviously are created in a light water reactor (LWR) faster than they are consumed. Thus, the plan, called GNEP by DOE, is to "burn" these materials in a reactor that has a greater neutron flux, probably a sodium-cooled breeder reactor. By "burn" we mean, convert these long-lived radionuclides to shorter-lived radionuclides. That is, this plan requires breeder reactors, which the U.S. does not have. Building these facilities would take time, research and money, especially since some of the technology has not been perfected yet. We discuss the individual radionuclides below.

Neptunium: After fuel dissolution, U and Pu is associated with the organic stream (kerosene and TBP), and the fission products are associated with the aqueous stream. Np-237 is partly associated with the U/Pu organic stream, but primarily is associated with the aqueous stream. Of all the radionuclides, Np-237 is probably the easiest to recover. For years, the DOE had been recovering Np-237 from spent fuel at the Savannah River Plant, then irradiating the Np-237 rods to create Pu-238, used for heat generators in satellites. Np-237 is therefore one radionuclide that can be successfully transmuted, but at a penalty in an LWR, that is, an LWR must have a greater amount of fissile U-235 and/or Pu-239+241 to compensate for the neutrons absorbed by Np-237. Under fast neutron bombardment, Np can fission; its critical mass is 55 kg. Thus, Np-237 must be safeguarded.

Americium/Curium: However, it is not sufficient to simply remove Np-237 from HLW, in order to reduce the repository burden since Am-241 decays to Np-237. Thus, the GNEP goal is also to separate Am and Cm from liquid HLW at the reprocessing stage. The separation efficiency must be on the order of 10,000, to sufficiently reduce the repository hazard.[6] This separation efficiency is not presently possible. Once separated, these minor actinides cannot simply be placed into an LWR, without simultaneously increasing the fissionable materials (U-235 and Pu-239 and Pu-241). The GNEP goal is therefore to place these actinides into a fast flux or breeder reactor, and transmute them to shorter-lived materials. This part of the process becomes quite murky. The only presently viable method is to store and dispose of specially prepared Am/Cm. That is, it does not appear that this part of the repository burden problem has been resolved, even in DOE's most optimistic view.

Technetium: Tc-99 has a long half-life and needs to be removed from HLW. A great deal of Tc-99 is created in an LWR, approximately 26 to 27 kg/GWe-yr, or 1.2 kg/MT[7]. Soluble TcO_4^- can be extracted from liquid HLW, but the insoluble Tc component cannot be easily separated. This radionuclide can be transmuted to shorter lived radionuclides, but its small cross-section requires high neutron fields, that is, a breeder reactor.

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[6] IAEA (2003)
[7] IAEA (2003)

Iodine: I-129 has a radiotoxicity comparable to the actinides. It occurs in liquid and gaseous forms in a reprocessing plant. About 7.1 kg/GWe-yr is produced in an LWR. At a reprocessing plant, I-129 is generally captured as a gas or particulate on silver zeolite beds, or contaminates the organic solution and is disposed of in a landfill. I-129 cannot be easily transmuted to shorter-lived materials in a light water reactor because of its small cross-section. DOE's plan for I-129 is similarly murky. The IAEA says that it can be disposed in the ocean.[8] It also can be disposed of in a HLW repository, but this defeats the purpose of separating I-129 from HLW.

This is the bottom line. In order to lessen the waste burden of a high-level waste repository, particularly, the long-lived hazard of high-level waste, two components must go together: an expensive research effort to increase the efficiency of separating actinides from high-level waste, and a large number of breeder reactors to "burn up" some of the separated radionuclides. It is still not clear how some of the actinides and I-129 will be handled.

This reprocessing scheme does not look feasible, and maybe that is the point. Perhaps this is a method for removing irradiated fuel from reactor sites, sending it to a national lab for reprocessing, to separate the plutonium for re-use. This would drop the waste burden onto the DOE. This would not solve the waste problem. It would simply move the problem from the utilities to the federal government.

Long-Term Storage vs Disposal

If irradiated fuel is not reprocessed, the alternatives are storing irradiated fuel at reactor sites or regional storage facilities or disposing irradiated fuel in a high-level waste repository. In choosing between long-term storage versus disposal of irradiated fuel, it should be recognized that all "solutions" pose risks. While the term "disposal" implies safety, it is not out of sight, out of mind. Disposal in the earth in an underground repository should be viewed as storage in an imperfect container. If a repository begins to fail, retrieval is not feasible. If a repository begins to leak, this would be the worst time to send workers into the repository for retrieval. On the other hand, irradiated fuel in dry storage can be retrieved and placed in another cask.

To secure irradiated fuel from potential sabotage, it is important that storage be hardened, to withstand any sabotage attack.

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[8] IAEA (2003)

Yucca Mountain was chosen for political, not scientifically defensible, reasons. Placing a repository in a geologically unstable region, with recent volcanic activity, was not a politically wise solution. Choosing a repository in a western state, when most of the irradiated fuel is produced in eastern states implies additional transportation miles and additional transportation risks. The risk due to potential transportation accidents or sabotage can be considerably lessened with long-term storage of irradiated fuel at reactor sites or regional storage sites. Transportation greatly increases sabotage vulnerability compared to hardened dry cask storage at reactor sites.

The Commission should also consider the political reality. Transportation from East Coast reactors to a western repository, like Yucca Mountain, implies a risk to 2/3rd's of the Congressional districts through which irradiated fuel would pass.

In sum, the Commission should recognize that reprocessing is not a waste management solution, that a repository in a western state increases the transportation risk due to accidents and sabotage, and that a repository itself poses a risk. In short, there may not be a Hollywood ending to high-level waste once it is produced.

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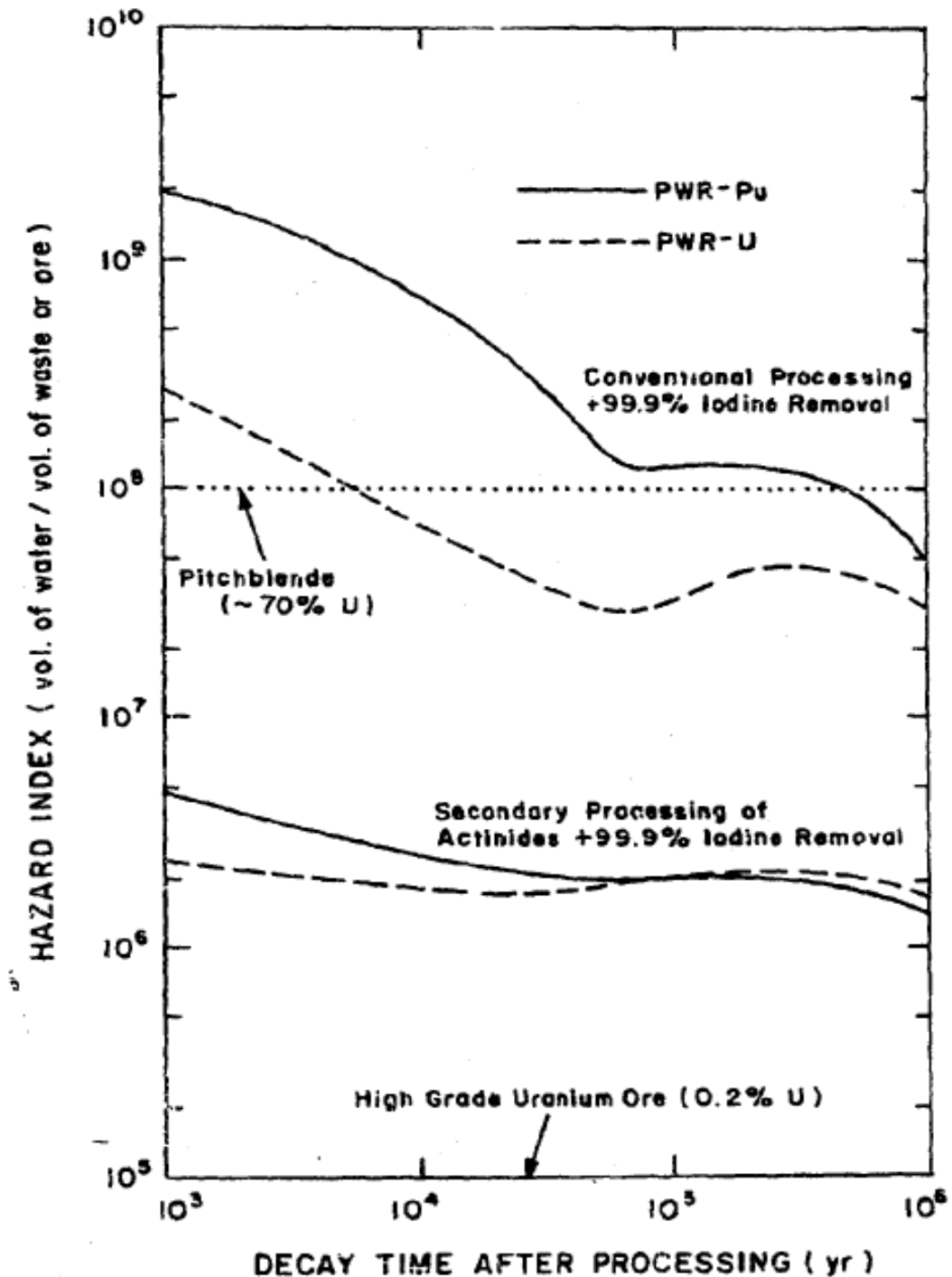
Table 1.   **PWR Spent Type E Fuel**

Radionuclides	U only		MOX only	
	kg	**%U**	**kg**	**%U**
U-234	2.99	0.0017	0.36	0.0044
U-235	148.39	0.89	22.61	0.275
U-236	126.03	0.72	2.97	0.036
U-237	0.2	0	0.1	0
U-238	17346	98.4	8204	99.7
Np-237	14.6		0.6	
Np-239	1.47		0.61	
	% Pu		**% Pu**	
Pu-238	5.46	3.3	10.84	3.43
Pu-239	96.22	57.5	110.78	35.1
Pu-240	40.11	24	84.89	26.9
Pu-241	19.11	11.4	60.29	19.1
Pu-242	6.53	3.9	48.97	15.5
Am-241	0.46		3.65	
Am-242	0.02		0.24	
Am-243	1.73		28.7	
Cm-242	0.19		1.31	
Cm-244	0.56		16.1	
Cm-245	0.03		1.78	
Cm-246	0.007		0.17	